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PHYSICAL ELEMENTARY COMPONENT FOR MODELING THE SENSORY - MOTRICITY : THE PRIMARY MUSCLE

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proprioceptive motricity - primary muscle - physical models - Cordis-Anima - force feedback gestural programmation - physical model path-planning

Abstract

This paper deals with the introduction of a proprioceptive motor component in Cordis-Anima modeler-simulator for physical objects.

The problem of the motor modelisation appeared while developing the method of the gestural programmation. This leads to the definition of the motricity elementary component which is called primary muscle. The primary muscle enables the inner control of the simulated physical object in real time. This control can be done either by an operator or by a program.

The primary muscle has been used in elementary scenes which demonstrate the proprioceptive motricity. Once the elementary moving object was found, we developed a physical model path-planning method by providing exteroceptive information to this moving object.

1. Introduction to the gestural programmation in the control of physical objects.

We aim at mastering the behaviour of an artificial moving object, which is more or less autonomous. In this paper, these objects will be called movings objects or vehicles, but the meaning is not restrictive.

To control a moving object, there are two thought processes : either the moving object can be teleoperated ; in which case the system is divided into a command device, driven by a human operator and an autonomous executive device ; or the artificial object is completely autonomous.

Teleoperation is a direct extension of a manual tool. It allows human beings to act in another environment from their own environment. This is particularly the case in virtual reality.

Autonomous systems are the privileged experimental field for Artificial Intelligence. Up until now, objects and environments were described by their geometrical characteristics, which leads to geometrical path-planning. If this method is valid for rigid objects or articulated objects with few degrees of freedom (DOF), it is unfeasible for deformable objects and environments.

Thanks to physical models, the problem of controlling moving objects can be handled without any discrimination between teleoperation and autonomy. Furthermore, the restriction concerning the object or environment nature (rigid or deformable) is removed. Inner interactions as well as interactions between objects are modeled in the same way with the constructive language Cordis-Anima. The operator will then be able to teleoperate this virtual object in the virtual physical universe with visual and gestural feedback. Gestural programmation consists of extracting information from a human's real command in a realistic situation, in order to create an automatic command generator.

2. Cordis-Anima

Cordis-Anima [LJC91] is a physical modeler-simulator developed by the ACROE team. It provides computer representation of a large variety of physical systems. It allows the production of sounds by simulation of physical structures (strings, sheets, for example), or to produce animations where objects have a physical behaviour.

As with any physical object, the objects described by Cordis-Anima can be seen, heard and physically manipulated. This modeling and simulation system is composed of a constructive language -to describe physical scenes, and a computer architecture environment, such as force feedback gestural transducers (FFGT) to act on the object and perceive it via the gestural channel. Simulations can be handled in real time with a 1kHz sampling frequency in order to perceive the force feedback instantaneously.

The Cordis-Anima system has opted for a "particle physics"system. The minimal element of matter is a punctual mass named <MAT> and forces are applied to it. Interactions, named <LIA> link two of these elements of matter to make up an object or a scene.

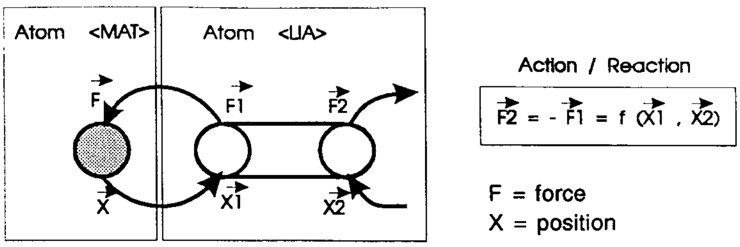

Figure 1 : Element of matter and Link

3. Proprioceptive Motricity

3.1. Concept of Proprioceptive Motricity

Today, several sorts of deformable and articulated rigid vehicles are modeled with the Cordis-Anima system [LJC91], [JLL91a], [JLL92], [LJL93]. Like any Cordis-Anima object, these vehicles are set in motion via two kinds of energy sources : natural energy sources, as in the instance of gravity and wind ; any attraction or repulsion ; and in the case of the human operator, with the force feedback system.

The command of virtual vehicles with the FFGT implies the modelling of a motor. The operator feeds the input into this motor which feeds back information about its internal status. This is the proprioceptive motricity, defined as follows : at the very elementary level, to motorize the simulated moving object means that the operator provides the motricity force, via the FFGT. The operator detects the vehicle resistance to his movement from the feedback. Thus, we can define the concept of sensory-motricity as the coupling between command and perception.

Note that, in order to correspond to a real function of the simulated object, the proprioceptive motor has got to be inside the object. For instance, pulling the vehicle by a string does not make up an internal motor.

3.2. A Physical model of Elementary Proprioceptive Motricity

"Elementary" means that we are looking for the smallest Cordis-Anima component which permits the sensory-motricity concept. We thought that this could be achieved with a <LIA> component (link between two elements of matter, also called masses). This component exerts two opposite forces to both elements of matter, leading to their relative motion. In the real world, it is the muscle that plays the role of exerting opposite forces on insertion points. This is why this <LIA> component will be named <u>muscle</u>.

Moreover, the opposite forces exerted on the masses must be proportional to the force exerted by the human operator on the FFGT key. This would be a direct link if the FFGT key was an L point (i.e. if its input was a position and its output a force). This scalar output force would then be converted into two opposite force vectors supported by the line that joins both masses. The position input of the FFGT would be the distance between the two masses.

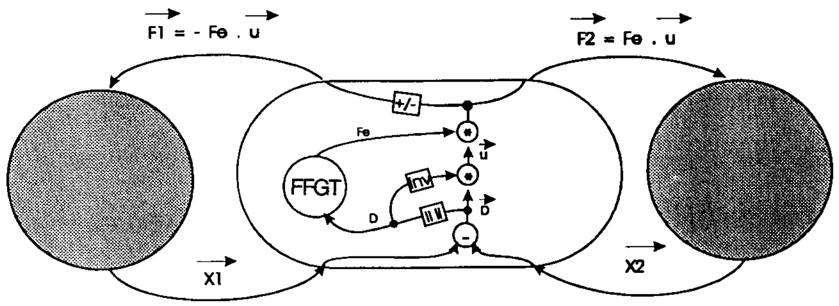

Figure 2 : The muscle with the FFGT considered as an L point

However, the FFGT has a force input and yields information about its position (this is an M point as opposed to an L point). Several solutions can be thought of for the conversion of this M point into an L point.

One hardware solution would consist of a position control of an FFGT key. The FFGT controlled in this way, has a position input and the feedback force could be measured : this is an L point.

Another solution using the Cordis-Anima modeler would consist of converting the FFGT M point into an L point via a <LIA> component. A 1D spring-damper fits this constraint well, since we wish that D (the distance between two elements of matter), leads to the FFGT position. This is a position control via the spring-damper. Then, it is necessary to choose the K and Z coefficients as high as possible in order to come close to the hardware solution, where the FFGT can be seen as an L point.

The second solution has been chosen, since it uses physical models.

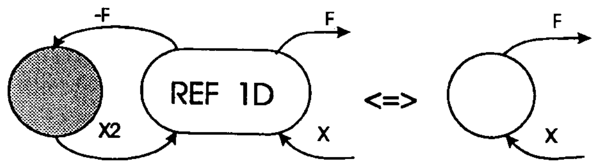

Figure 3 : Conversion from an M point to an L point with a spring-damper

Consequently,we give the general representation of the primary muscle, as follows : a sort of <LIA> component with three connections, connecting two 3D masses and one 1D mass, the FFGT. This is a new Cordis-Anima basic component that allows switching from 1D space to multidimensional space. In our case, 1D space is the muscular manipulation space and the simulated objects move in the multidimensional space. This new component has been named Radial Physical Coupling Link (RPCL).

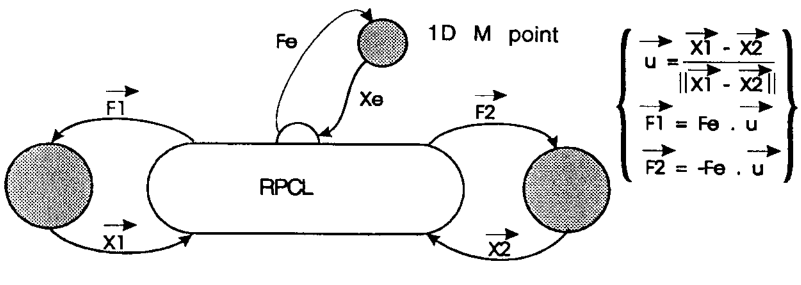

Figure 4 : Radial Physical Coupling Link

3.3. Qualitative functioning of the muscle

The primary muscle suits its role of sensory-motricity. The scene can be pictured as if the operator, who exerts opposite forces between the floor and the FFGT key, would be inside the muscle and would apply these forces between both 3D connected masses.

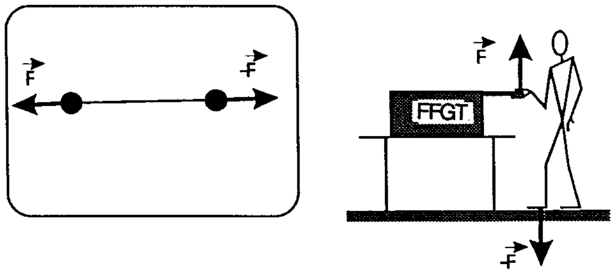

Figure 5 : Qualitative functioning of the muscle

However, in the real world, a joint is moved by two antagonist muscles that can only exert a one-way force. Thus, for a better analogy, the operator should always press on the FFGT key and not pull it. In this way, two masses will be linked by two antagonist primary muscles.

4. Smallest scene to implement Elementary Proprioceptive Motricity

4.1. Choice of the dimension

It is easiest to conceive of a one dimensional scene. The 1D vehicle will have to be able to move on a line and to choose its direction.

4.2. Choice of the moving object

The smallest 1D vehicle is composed of two masses, connected via a <LIA> component whose forces are applied by the operator. The muscle fits this function well. Furthermore, inertia and external forces of both masses will be perceived by the operator, as expected.

As we are working in 1D space, a single DOF vehicle's command is a necessary and sufficient condition to choose the moving direction and to provide motricity.

4.3. A non-linear environment

Up until now, if the vehicle we have just described is moving in a 1D environment with linear viscosity, the gravity centre is not able to move. That is the reason why it is necessary to work in a 1D environment with non-linear viscosity. In our demonstrations, viscosity piecewise linear functions have been used to describe the environment.

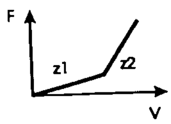

Figure 6 : Viscosity piecewise linear function

To achieve effective locomotion, the three following characteristics are essential :

- the vehicle must be in physical interaction with an environment,
- the interaction must be dissipative,
- the interaction must be non-linear.

Indeed, the locomotive organ leans on the environment to move. A walker leans on the floor : there are two non-linear interactions, collision and dry friction. Interaction with the environment is a fundamental component of the locomotion. In other studies, this aspect is generally not taken into account, as far as motricity and locomotion models are concerned.

4.4. The 1D Elementary Moving Object or "Tadpole"

And now, all the elements are given : the gravity centre of the vehicle's two masses moves, provided that the two masses are not in the same viscosity area (see Figure 6 above). Subsequently, it is necessary to insert a dissymmetry into the vehicle : a heavy head which stays in the area defined by the viscosity z1, and a foot with a weak mass that moves from one area to the other. To let the vehicle move, the muscle must be controlled with rapid extension and slow contraction, so that the foot is in the z2 area during the extension and in the z1 area during contraction. That way, the vehicle moves and can change its direction : it is both a necessary and sufficient condition that the vehicle be a physical object with a muscle, a big head and a foot, in a non-linear viscosity environment. This is the reason why this vehicle is named "tadpole".

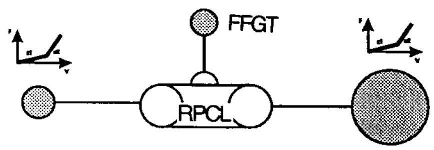

Figure 7 : The tadpole model

4.4. The 2D Elementary Vehicle or "Frog"

The 2D elementary vehicle consists of 3 masses, since it is the minimum to define a two dimensional object. It is composed of 2 muscles which provide 2 DOF, as far as motricity is concerned. As the 2D vehicle should have the same behaviour as the tadpole, it is called a "frog" and is structured with a head whose mass is bigger than that of the two feet. Thus, the feet can move from one viscosity area to the other.

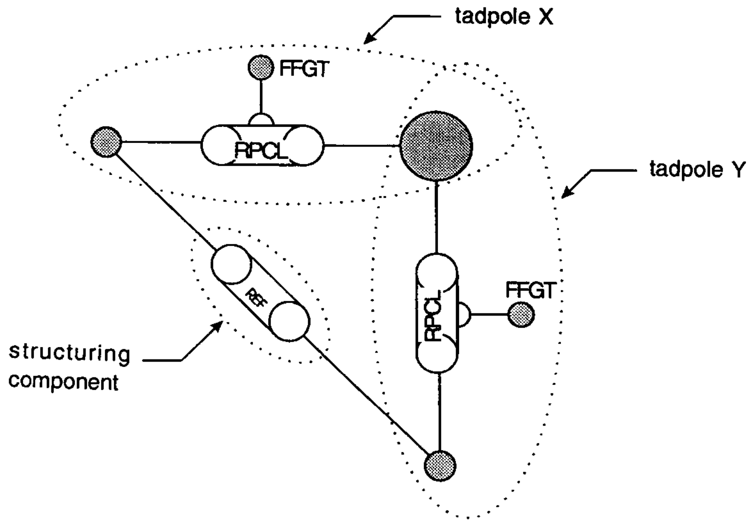

Figure 8 : The frog model

The spring-damper linking the feet is a structuring element, necessary to keep the vehicle's geometry. To move straight forward, moving the muscles in the same way is sufficient, and exerting wider movements on one of the feet makes it possible to turn.

5. Real-time demonstration of Sensory-motricity

A real-time implementation of various elements, necessary for this proprioceptive motricity experimentation has been produced. That way, we developed the frog model. It is controlled by two FFGT keys. We aim at ensuring the force feedback quality, role and necessity. The force feedback quality is measured via the collisions' and environment's perception during locomotion, as well as by the obstacle's resistance and moving object inertia perception. A video-tape is available at the ACROE.

6. Application to path-planning

6.1. Physical model path-planning

Path-planning with the help of physical models is one of the numerous Cordis-Anima applications experimented in the ACROE laboratory. We can oppose the latter to the geometrical path-planning because of the kind of scene we are studying and the path-planning's method. The aim is to find a really practicable path where a given vehicle can move with no a priori, concerning the environmental aspect.

6.2. Darwin's bowl

Previous works of the ACROE team -on physical model path-planning, have introduced the concept of a moving target, which allows guidance of a vehicle with or without the help of an operator [JLL91a] [JLL92] [LJL93]. In the method we introduce in this paper, as in previous methods, generalized obstacles block the obstacles to be avoided, so that the latter are unreachable to the moving object. In the same way, a physical target is used to attract the vehicle. On the other hand, now, with the help of the muscle, vehicles own their internal motricity force so that they are capable of bypassing obstacles.

Then, to find the paths, a heterogeneous colony of tadpoles (with dispersion or parameters) is launched, and only the tadpoles that reach the target are selected.We determine the practicable path by following the tadpoles paths. The tadpoles' motion is due to the target attraction and to their own motricity.

In this case, we apply the Darwin strategy, since only the most qualified tadpoles reach the goal. This method has been implemented and gives convincing results even with mazes. There is failure when no tadpole reaches the target beyond a certain parameters dispersion threshold of the vehicle's motricity.

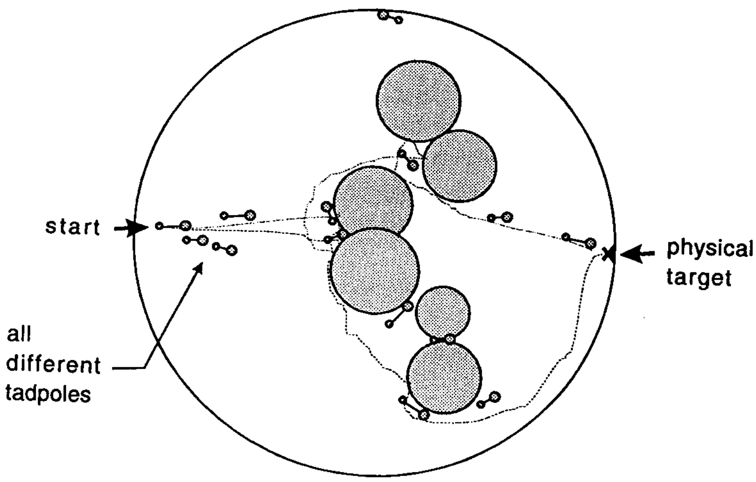

Figure 9 : Darwin's bowl

7. Conclusion and Future Prospects

The primary muscle brings the tool needed for the control of moving objects : the development of the force feedback gestural programmation concept.

As far as the autonomy is concerned, motion control by physical target attraction as presented above, is not satisfying. Indeed, the vehicle's movement is not only due to its motricity, since the target attraction is taken into account. However, a relationship between the target and the moving object is required in all cases.

Notice that, when we link a target to a moving object with a spring, the moving object receives information about its environment far away. Thus, the spring is the physical component that holds the distance information. A more general interpretation would then be to consider that we give exteroceptive information to the moving object to control the frog's muscles.

In this case, the idea is to put a fictive spring between the target and the moving object. The frog's muscles will be controlled by the distance information furnished by this fictive spring, via a physical transformer device. The muscles command will be generated, on the one hand, by the proprioceptive and immediate environment information, and on the other hand, by the exteroceptive information (direction and distance to the target). The muscle's control device belongs to the Artificial Intelligence subject. Nevertheless, the device owns necessarily a physical model part connected to the muscle and to the fictive spring. Though the device's functions belong to the AI, it could be entirely implemented with a physical model. As a result, the physical model of the moving object would be driven by a brain's physical model. The question we may ask is to know which planning problems could be entirely solved by physical models, without resorting to the Artificial Intelligence.

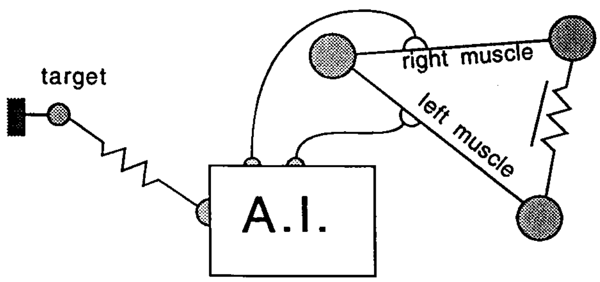

Figure 10 : Introduction of Artificial Intelligence in physical models

The muscle is the Cordis-Anima physical component which permits the introduction of traditional AI modules into a physical model simulator.

Our objective is to put the biggest amount of "reflex intelligence" in the vehicle, in order to reduce the part solved by the AI, as much as possible. For example, the human visual system or the speach recognition system own pre-treatments that can detect various events and release reflex actions without the need of cognitive processes.

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